ORAU TEAM
Dose Reconstruction
Project for NIOSH

Oak Ridge Associated Universities I Dade Moeller & Associates I MJW Corporation

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☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/13/2007	00	First approved issue. New technical information bulletin for assignment of LLNL internal doses based on coworker bioassay data. Revised second to last sentence in Section 5.2.1 to indicate that workers exposed to uranium in 1952 through 1957 were not unmonitored if they had uranium bioassay in more recent years. Other minor changes occurred in response to internal review. Incorporates NIOSH formal review comments. Added dates of operation of AVLIS to Section 4.1. Deleted "1981" from the second sentence, 5th paragraph under Section 4.1. In same paragraph, indicated that "all" samples were excluded for persons with more than 20 samples. Added Attributions and Annotations section. There is no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Donald E. Bihl.

TABLE OF CONTENTS

SECTION **TITLE** **PAGE**

LIST OF TABLES

TABLE **TITLE** **PAGE**

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AVLIS Atomic Vapor Laser Isotope Separation

DOE U.S. Department of Energy

GSD geometric standard deviation

hr hour

ICRP International Commission on Radiological Protection
IMBA Integrated Modules for Bioassay Analysis

L liter
LLNL Lawrence Livermore National Laboratory

MDA minimum detectable activity

NIOSH National Institute for Occupational Safety and Health

ORAUT Oak Ridge Associated Universities team

pCi picocurie

TBD technical basis document
TIB technical information bulletin

U.S.C. United States Code

μm micrometer

yr year

§ Section

1.0 INTRODUCTION

Technical information bulletins (TIBs) are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

In this document, the word “facility” is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy (DOE) facility” as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384l(5) and (12)].

2.0 PURPOSE

Some employees at DOE sites were either not monitored for intakes of radioactive material or the records of such monitoring are missing or incomplete. In such cases, data from monitored coworkers can be used to estimate an individual’s possible exposure. The purpose of this document is to provide monitored coworker information for calculating and assigning intakes to employees of the Lawrence Livermore National Laboratory (LLNL) for whom no or insufficient bioassay monitoring records exist.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 6.0.

3.0 OVERVIEW

Analysis of Coworker Bioassay Data for Internal Dose Assignment (ORAUT 2005a) describes the general process for analyzing bioassay data for the assignment of doses based on coworker results.

Bioassay results for LLNL were obtained as a copy of the site’s MAPPER database converted to an Excel spreadsheet along with a cover letter explaining characteristics of the database and pointing out possibilities of data recording errors that might exist in the database (Mansfield 2006a). As sent to Oak Ridge Associated Universities Project Team (ORAUT), the MAPPER database had approximately 34,900 records. It contained no *in vivo* counting results and had only a few of the many tritium urinalysis results obtained throughout the operation of the Laboratory. The *in vivo* counting results were not available electronically and, therefore, were not analyzed as a coworker database. (*In vivo* results for individual Energy Employees are included in the files sent to NIOSH from LLNL.) It also proved infeasible to obtain the rest of the tritium urinalyses results from LLNL; discussion of the tritium dose database is reserved.

The principal radionuclides with potential for intakes at LLNL were tritium, isotopes of plutonium in a weapons-grade mixture, isotopes of uranium in mixtures typical of depleted uranium, natural uranium or slightly enriched uranium (to 5%), various transuranic radionuclides, activation products, and fission products (ORAUT 2005b). The MAPPER database had small numbers of analyses for other radionuclides, such as ^{241}Am, curium, “TRU;” however, the numbers were too small for statistical analysis. Generally, LLNL used the gross alpha analysis to screen for intakes of transuranic radionuclides with follow-up analyses being more specific for the radionuclide of concern.

The urinalysis data chosen for this coworker study because of general applicability and number of measurements were for plutonium, uranium, gross alpha, gross beta, and an analysis labeled MFP. Two previous bioassay laboratory managers confirmed that the gross beta results and the MFP results were from the same procedure and should be treated as the same (Bihl 2006, Mansfield 2006b). The tritium dose data were also analyzed. For revision zero of this document, the analyses of the plutonium, gross alpha, gross beta, and tritium datasets were reserved.

The statistical analyses of the bioassay data for each radionuclide were performed in accordance with the internal dosimetry coworker TIB (ORAUT 2005a) and the procedure, *Generating Summary Statistics for Coworker Bioassay Data*, (ORAUT 2006a). The resultant values were input to the Integrated Modules for Bioassay Analysis (IMBA) computer program and a fit to the data for each of the five analyzed groups at the 50th- and 84th-percentile values was performed to obtain intake rates for assignment of dose distributions.

4.0 DISCUSSION OF THE DATASETS

4.1 URANIUM

MAPPER had uranium urinalysis data from 1958 to 1996. Nearly all of the results were reported as U238 in units of µg/L. The LLNL cover letter indicates that the results actually represent total uranium (Mansfield 2006a). According to the technical basis document (TBD), most uranium exposure was to depleted or natural uranium. The Atomic Vapor Laser Isotope Separation (AVLIS) project converted kilogram quantities of natural uranium to slightly enriched uranium, up to 5%, as a demonstration plant. AVLIS operated in 1998 and 1999. There was another project involving highly enriched uranium in the 1990s. When identified in MAPPER, results from workers on these projects were excluded from the uranium dataset because of the higher specific activity of uranium on that project (31 results). Uranium results were left in the units of µg/L for the statistical analysis and curve fitting.

The uranium dataset has no negative (i.e., <0) results. Minimum detectable activities (MDAs) for the uranium analysis methods were not provided in the LLNL cover letter. The TBD lists the MDA as 4 µg/L through 1975, 1 µg/L for 1976 through 1986, and 0.04 µg/L for 1987 through 1999; however, these MDAs came from industry-wide norms rather than LLNL specific documentation (ORAUT 2006b). Most of the results less than 1 µg/L were recorded as zero prior to 1974. In 1974, the database shows a distinctly different pattern, with an overall decrease in the general magnitude of the results, a lower reporting level at around 0.01 µg/L, and sufficient results between 0.01 to 1 µg/L to support a reasonably normal or lognormal pattern implying that a change to a more sensitive analysis technique took place. The MDA in 1985 was stated in one document as about 0.3 µg/L (Gibson 1985).

The zero results were included in the ranking of the data but not the curve fitting. In several years prior to 1974, there were a few results recorded with values between 1 and zero µg/L. Because there were just a few of these and not in all years, they seemed to be anomalous recordings relative to the 1 µg/L reporting level. Because they might have been misrecorded data, such as misplaced decimals or incorrect unit conversion, and because they were clearly anomalous when included in the lognormal plots of the results, these results were excluded from the final annual datasets. There were 37 of these results throughout the period 1962 through 1973. Excluding these results had only small effects on the 50th and 84th percentiles.

The uranium dataset had entries from recounts on the same sample and entries showing multiple same-day samples from a given worker. The recounted samples were identified as having identical information, including sample number, but different results and different uncertainty. The multiple same-day samples were indicated by having the same worker identification and sample dates, however, the sample numbers were different, often by one digit. Because two counts on a single sample or two samples from a given worker on the same day produces a bias when compared to other workers' samples that were given only a single count, the multi-counted samples were replaced by the average of the multiple counts.

Duplicate entries that were obvious and samples marked by LLNL as baselines or quality control samples were excluded [1].

Table 4-1 lists the time intervals for separate statistical analyses. Intervals were chosen to obtain approximately 100 results or more per interval; however, 1967 had only 51 results and 1971 had only 34 results. (The median and 84th-percentile values for 1971 were also much lower than surrounding years, perhaps indicating that there was little work with uranium at the site in 1971.) The statistical parameters for each interval, e.g., 50th and 84th percentiles, were assigned to the midpoint of the interval.

Table 4-1. Time intervals for statistical analysis of uranium urine samples.

Calendar year	**Analysis interval**
1958	Year
1959−1961	Treated as a single interval
1962–1964	Treated as a single interval
1965–1974	Year
1975–1986	Six months
1987−1996	Three months

4.2 PLUTONIUM (RESERVED)

4.3 GROSS ALPHA (RESERVED)

4.4 GROSS BETA AND MFP (RESERVED)

4.5 ANALYSIS

For each of the radionuclide groups above, a lognormal distribution for the data in the intervals specified in Tables 4-1 to 4-4 was assumed [2]. (Tables 4-2 through 4-4 are reserved.) The 50th- and 84th-percentile values were calculated using the method described in ORAUT (2006a). Table A-1 in Attachment A shows the statistical analysis results for uranium.

5.0 INTAKE MODELING

5.1 ASSUMPTIONS

All urinalysis results were assumed to be representative of a full-day (24-hr) urinary excretion or were normalized to be representative of a full day before creating the lognormal plots with the exception of the uranium data, which were normalized to daily excretion prior to intake modeling [3]. Each result used in the intake calculation was assumed to have a normal distribution and a uniform absolute error of 1 was applied to all results, which weighted all results equally [4]. A chronic exposure pattern was assumed unless the data clearly showed a sharp, short-term, increase in excretion [5]. Intakes were assumed to be from inhalation using a default breathing rate of 1.2 m^3/hr and a 5-μm activity median aerodynamic diameter particle size distribution [6].

When calculating doses to individuals from bioassay data, a GSD of 3 has been used to account for biological variation and uncertainty in the models. It was considered inappropriate to assign a value less than 3 for the coworker data. Therefore, a GSD of 3 was assigned for any intake period where the calculated GSD was <3 [7].

5.2 BIOASSAY FITTING AND INTAKES

The IMBA Expert ORAU-Edition, Version 4.0.9 computer program was used to fit the bioassay results to a series of chronic inhalations. The intake assumptions were based on observed patterns in the bioassay data. Intervals with constant chronic intake rates were chosen by selecting periods during which the bioassay results were of similar magnitudes. A new chronic intake period was started where the data indicated a significant sustained change in the results [8]. The effective bioassay dates used in IMBA to calculate the intake rates were the midpoints of the sampling time periods [9]. The 50th- and 84th-percentile excretion values were fit as independent datasets producing separate 50th- and 84th-percentile intakes [10]. The geometric standard deviations were calculated as the ratio of the 84th- to the 50th-percentile intakes for each intake interval [11].

The TBD does not specify inhalation absorption types for the various radionuclide or group of radionuclides; therefore, the bioassay results were entered into IMBA with assumed lung absorption types chosen to be consistent with International Commission on Radiological Protection (ICRP) Publication 68 (ICRP 1993). Attachment A shows the resultant 50th-percentile intakes as plots. The bioassay data used in the fits are shown as solid blue dots (●) (dark spots when printed) and data that are not used in the fits are shown as red dots (●) (light dots when printed).

Type S compounds have very long radiological half-lives and the materials are retained in the body for long periods; therefore, the excretion results for different chronic intake periods are not independent for type S materials. For example, an intake in the 1950s could contribute to urinary excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked at LLNL for relatively short periods, each chronic intake of type S material was independently fit using only the bioassay results from the single intake period. This results in an overestimate of intake rates for workers who were exposed to type S compounds for long periods.

5.2.1 Uranium

The 50th- and 84th-percentile uranium urinary excretion concentrations in μg/L were converted to mg/day assuming a daily urine volume of 1.4 liter per day (ICRP 1974). These data are shown in Table A-1. The intakes were determined from the mg/d excretion values. For ease of use by dose reconstructors, the intakes were also converted to activity using the specific activity of natural uranium (682 pCi/mg), which is favorable to claimants relative to using the specific activity of depleted uranium. While workers at LLNL may not have been chronically exposed to natural uranium, chronic intakes will approximate a series of acute intakes with unknown intake dates. Plots of the fits of models to urinary excretion are shown in Figures A-1 through A-24.

The intake rates, geometric standard deviations, and time periods in which they are applicable are given in Table 5-1. Use the intakes in pCi/d assuming all the activity is from ^{234}U, which is favorable to claimants.

Table 5-1. Uranium mass and activity intake rates for four different time periods.

Type	Dates	50th Percentile (mg/day)	84th Percentile (mg/day)	50th Percentile (pCi/day)	84th Percentile (pCi/day)	GSD
F	1/1/58-12/31/73	2.51E-02	5.81E-02	1.71E+01	3.96E+01	2.32[a]
F	1/1/74-12/31/87	1.65E-04	8.52E-04	1.13E-01	5.81E-01	5.16
F	1/1/88-12/31/96	2.87E-04	3.73E-04	1.96E-01	2.54E-01	1.30[a]
M	1/1/58-12/31/73	1.03E-01	2.39E-01	7.04E+01	1.65E+02	2.32[a]
M	1/1/74-12/31/87	6.76E-04	3.49E-03	4.61E-01	2.38E+00	5.16
M	1/1/88-12/31/96	1.20E-03	1.582E-03	8.16E-01	1.08E+00	1.32[a]
S	1/1/58-12/31/73	1.24E+00	2.93E+00	8.49E+02	1.99E+03	2.35[a]
S	1/1/74-12/31/87	8.55E-03	4.19E-02	5.83E+00	2.86E+01	4.90
S	1/1/88-12/31/96	1.75E-02	3.01E-02	1.19E+01	2.05E+01	1.72[a]

a. Use the default GSD of 3.0 instead of the calculated GSD.

There were no bioassay results for uranium prior to 1958 in the MAPPER database and, according to the laboratory manager circa 1958, few or none may have been obtained, so workers exposed to uranium during 1952 through 1957 who did not have subsequent uranium bioassay would be considered unmonitored. Guidance for how to assign intakes of uranium during that period is reserved.

5.3 PLUTONIUM (RESERVED)

5.4 GROSS ALPHA (RESERVED)

5.5 GROSS BETA/MFP (RESERVED)

6.0 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional References, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database.

[1] Bihl, Donald E. ORAU Team. Principal Health Physicist. January 2007.
Duplicate entries bias the dataset and provide no useful information concerning coworker exposures. Quality control samples are spiked samples used to monitor laboratory performance against known quantities of the analyte; they are not excreta samples from workers. See also ORAUT-PROC-0095, "Generating Summary Statistics for Coworker Bioassay Data."

[2] Lochamy, Joseph C. ORAU Team. Senior Health Physicist. February 2007.
Per ORAUT-PROC-0095, “Generating Summary Statistics for Coworker Bioassay Data.”

[3] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
The uranium results were recorded as μg/L and the statistical analyses were performed in those units. However, the IMBA software requires that all excreta data be entered as total excretion per day; hence, the statistical parameters were converted to excretion per day before intake calculations were made using IMBA.

[4] Brackett, Elizabeth M. ORAU Team. Principal Internal Dosimetrist. February 2007.
The uniform absolute error of 1 weights all results equally; other fitting schemes weight high values or low values disproportionally. Because the median and 84th percentile values were determined from statistical analysis of many samples in each interval, there was no a *priori* reason to weight results from any one interval over another.

[5] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Per ORAUT-OTIB-019, “Analysis of Coworker Bioassay Data for Internal Dose Assignment.”

[6] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
The breathing rate and particle size distribution are project default values to be used unless site-specific information indicates otherwise. No information has been found concerning intakes at LLNL that shows that the default values should not be used. See, for instance, OCAS-IG-002, “Internal Dose Reconstruction Implementation Guide,” and ICRP Publication 66, “Human Respiratory Tract Model for Radiological Protection.”

[7] Bihl, Donald E. ORAU Team. Principal Health Physicist. February 2007.
The minimum GSD of 3 is established in ORAUT-OTIB-0060, “Internal Dose Reconstruction.” It reflects the overall uncertainty associated with biokinetic modeling as well as usual radiochemical analysis, and indicates that even though the spread in coworker excreta results for a given population (e.g., a year of excreta samples) can have a GSD of <3, the uncertainty of intakes determined using the biokinetic models is no less than 3.

[8] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
The first four sentences of this paragraph explain how the intakes were calculated. The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist.

[9] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Use of the midpoint of the time period represented by the excreta data point is established in ORAUT-OTIB-019, “Analysis of Coworker Bioassay Data for Internal Dose Assignment,” and is standard practice for assigning chronic intakes or acute intakes with unknown dates. See, for instance, HPS-N13.39-2001, “Design of Internal Dosimetry Programs.”

[10] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Per ORAUT-OTIB-019, “Analysis of Coworker Bioassay Data for Internal Dose Assignment.”

[11] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Per ORAUT-OTIB-019, “Analysis of Coworker Bioassay Data for Internal Dose Assignment.”

[12] Lochamy, Joseph C. and Bihl, Donald E. ORAU Team. Senior Health Physicist and Principal Health Physicist. February 2007.
Table was compiled by Don Bihl from data generated by Joe Lochamy as explained in Section 4.5 and ORAUT-PROC-095.

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Gibson, T., 1985, *Discipline Action Plan; Radiation Safety Program for Site 300*. [SRDB Ref. ID: 16037]

ICRP (International Commission on Radiological Protection), 1974, *Report of the Task Group on Reference Man*, Publication 23, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1993, *Report of a Task Group of ICRP Committee II on Dose Coefficients for Intakes of Radionuclides by Workers*, Publication 68, Pergamon Press, Oxford, England.

Mansfield, W. G., 2006a, Letter from W. Gary Mansfield, LLNL, to Jennifer L. Hoff, ORAUT, “Copy of LLNL ‘MAPPER’ Bioassay Results Database,” May 17. [SRDB Ref. ID 28120]

Mansfield, W. G., 2006b, “Fwd; Re; Fwd; Questions for Gary Mansfield,” electronic mail message from W. Gary Mansfield, LLNL, to Don E. Bihl, PNNL, September 28. [SRDB Ref. ID 26886]

ORAUT (Oak Ridge Associated Universities Team), 2005a, *Analysis of Coworker Bioassay Data for Internal Dose Assignment*, ORAUT-OTIB-0019, Rev. 01, Oak Ridge, Tennessee.

ORAUT (Oak Ridge Associated Universities Team), 2005b, *Lawrence Livermore National Laboratory – Site Description*, ORAUT-TKBS-0035-2, Rev. 00, Oak Ridge, Tennessee.

ORAUT (Oak Ridge Associated Universities Team), 2006a, *Generating Summary Statistics for Coworker Bioassay Data,* ORAUT-PROC-0095, Rev. 00, Oak Ridge, Tennessee.

ORAUT (Oak Ridge Associated Universities Team), 2006b, *Lawrence Livermore National Laboratory – Occupational Internal Dose*, ORAUT-TKBS-0035-5, Rev. 01, Oak Ridge, Tennessee.

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS

Table A-1. Uranium urine bioassay data for 50th and 84th percentiles in units of μg/L and mg/day along with the time period and effective bioassay date, 1958 through 1996 [12].

Year	Effective bioassay date	50th[a] (ug/L)	84th[b] (ug/L)	50th[a] (mg/day)	84th[b] (mg/day)
1958	6/30/1958	6.886E+00	1.391E+01	9.640E-03	1.948E-02
1959-61	6/30/1960	6.128E+00	1.479E+01	8.580E-03	2.070E-02
1962-64	6/30/1963	5.773E+00	1.350E+01	8.082E-03	1.890E-02
1965	6/30/1965	7.611E+00	1.539E+01	1.066E-02	2.155E-02
1966	6/30/1966	1.615E+00	6.241E+00	2.261E-03	8.737E-03
1967	6/30/1967	6.910E+00	1.401E+01	9.674E-03	1.961E-02
1968	6/30/1968	5.415E+00	9.337E+00	7.581E-03	1.307E-02
1969	6/30/1969	3.676E+00	7.727E+00	5.146E-03	1.082E-02
1970	6/30/1970	1.913E+00	5.412E+00	2.678E-03	7.577E-03
1971	6/30/1971	9.164E-01	3.893E+00	1.283E-03	5.450E-03
1972	6/30/1972	8.316E+00	2.025E+01	1.164E-02	2.835E-02
1973	6/30/1973	4.312E+00	1.332E+01	6.036E-03	1.865E-02
1974	6/30/1974	4.574E-02	2.614E-01	6.405E-05	3.660E-04
1975 S1[c]	3/31/1975	6.246E-02	1.869E-01	8.745E-05	2.617E-04
1975 S2[c]	9/30/1975	7.562E-02	2.951E-01	1.059E-04	4.132E-04
1976 S1[c]	3/31/1976	3.083E-02	2.092E-01	4.317E-05	2.928E-04
1976 S2[c]	9/30/1976	2.754E-02	1.786E-01	3.856E-05	2.500E-04
1977 S1[c]	3/31/1977	2.109E-02	1.026E-01	2.953E-05	1.436E-04
1977 S2[c]	9/30/1977	2.419E-02	1.898E-01	3.386E-05	2.657E-04
1978 S1[c]	3/31/1978	3.272E-02	1.654E-01	4.581E-05	2.316E-04
1978 S2[c]	9/30/1978	3.315E-02	1.716E-01	4.641E-05	2.402E-04
1979 S1[c]	3/31/1979	2.137E-02	1.069E-01	2.988E-05	1.497E-04
1979 S2[c]	9/30/1979	3.709E-02	1.743E-01	5.193E-05	2.440E-04
1980 S1[c]	3/31/1980	2.477E-02	2.750E-01	3.468E-05	3.850E-04
1980 S2[c]	9/30/1980	8.372E-03	6.439E-02	1.172E-05	9.015E-05
1981 S1[c]	3/31/1981	9.337E-03	8.276E-02	1.307E-05	1.159E-04
1981 S2[c]	9/30/1981	8.418E-02	3.658E-01	1.179E-04	5.121E-04
1982 S1[c]	3/31/1982	3.963E-02	1.981E-01	5.548E-05	2.773E-04
1982 S2[c]	9/30/1982	8.179E-02	3.613E-01	1.145E-04	5.058E-04
1983 S1[c]	3/31/1983	2.842E-02	2.227E-01	3.976E-05	3.118E-04
1983 S2[c]	9/30/1983	3.694E-02	2.037E-01	5.172E-05	2.852E-04
1984 S1[c]	3/31/1984	2.784E-02	1.550E-01	3.898E-05	2.170E-04
1984 S2[c]	9/30/1984	4.755E-02	1.589E-01	6.657E-05	2.224E-04
1985 S1[c]	3/31/1985	3.331E-02	2.177E-01	4.663E-05	3.048E-04
1985 S2[c]	9/30/1985	2.855E-02	1.097E-01	3.996E-05	1.536E-04
1986 S1[c]	3/31/1986	2.012E-02	1.371E-01	2.817E-05	1.919E-04
1986 S2[c]	9/30/1986	5.117E-03	5.037E-02	7.164E-06	7.051E-05
1987 Q1[c]	2/15/1987	6.010E-03	5.424E-02	8.414E-06	7.594E-05
1987 Q2[c]	5/15/1987	1.115E-02	6.624E-02	1.561E-05	9.273E-05
1987 Q3[c]	8/15/1987	2.036E-02	1.049E-01	2.850E-05	1.469E-04
1987 Q4[c]	11/15/1987	1.902E-02	1.228E-01	2.663E-05	1.719E-04
1988 Q1[c]	2/15/1988	1.381E-02	1.152E-01	1.934E-05	1.613E-04
1988 Q2[c]	5/15/1988	6.777E-02	1.583E-01	9.487E-05	2.217E-04
1988 Q3[c]	8/15/1988	6.883E-02	1.656E-01	9.636E-05	2.318E-04
1988 Q4[c]	11/15/1988	1.036E-01	2.746E-01	1.450E-04	3.844E-04
1989 Q1[c]	2/15/1989	7.946E-02	1.877E-01	1.112E-04	2.628E-04
1989 Q2[c]	5/15/1989	1.044E-01	2.581E-01	1.462E-04	3.614E-04
1989 Q3[c]	8/15/1989	7.688E-02	2.156E-01	1.076E-04	3.019E-04
1989 Q4[c]	11/15/1989	1.041E-01	2.834E-01	1.457E-04	3.968E-04
1990 Q1[c]	2/15/1990	5.557E-02	1.424E-01	7.780E-05	1.994E-04
1990 Q2[c]	5/15/1990	4.668E-02	1.194E-01	6.536E-05	1.672E-04
1990 Q3[c]	8/15/1990	4.637E-02	1.017E-01	6.492E-05	1.424E-04
1990 Q4[c]	11/15/1990	5.328E-02	8.954E-02	7.459E-05	1.254E-04
1991 Q1[c]	2/15/1991	7.233E-02	1.348E-01	1.013E-04	1.887E-04
1991 Q2[c]	5/15/1991	8.435E-02	1.587E-01	1.181E-04	2.222E-04
1991 Q3[c]	8/15/1991	6.278E-02	1.109E-01	8.789E-05	1.552E-04
1991 Q4[c]	11/15/1991	3.915E-02	7.684E-02	5.481E-05	1.076E-04
1992 Q1[c]	2/15/1992	3.836E-02	7.151E-02	5.371E-05	1.001E-04
1992 Q2[c]	5/15/1992	3.665E-02	6.038E-02	5.131E-05	8.453E-05
1992 Q3[c]	8/15/1992	4.188E-02	7.383E-02	5.863E-05	1.034E-04
1992 Q4[c]	11/15/1992	3.108E-02	4.560E-02	4.351E-05	6.383E-05
1993 Q1[c]	2/15/1993	3.576E-02	5.452E-02	5.006E-05	7.633E-05
1993 Q2[c]	5/15/1993	4.383E-02	6.672E-02	6.136E-05	9.340E-05
1993 Q3[c]	8/15/1993	4.338E-02	6.845E-02	6.073E-05	9.583E-05
1993 Q4[c]	11/15/1993	5.259E-02	7.099E-02	7.362E-05	9.939E-05
1994 Q1[c]	2/15/1994	4.764E-02	6.450E-02	6.670E-05	9.030E-05
1994 Q2[c]	5/15/1994	4.321E-02	6.539E-02	6.049E-05	9.155E-05
1994 Q3[c]	8/15/1994	5.066E-02	7.457E-02	7.093E-05	1.044E-04
1994 Q4[c]	11/15/1994	5.338E-02	7.858E-02	7.473E-05	1.100E-04
1995 Q1[c]	2/15/1995	6.468E-02	9.702E-02	9.055E-05	1.358E-04
1995 Q2[c]	5/15/1995	5.128E-02	7.838E-02	7.180E-05	1.097E-04
1995 Q3[c]	8/15/1995	4.628E-02	6.613E-02	6.480E-05	9.258E-05
1995 Q4[c]	11/15/1995	4.706E-02	7.429E-02	6.588E-05	1.040E-04
1996 Q1[c]	2/15/1996	5.239E-02	9.028E-02	7.335E-05	1.264E-04
1996 Q2[c]	5/15/1996	4.861E-02	8.392E-02	6.806E-05	1.175E-04
1996 Q3[c]	8/15/1996	5.534E-02	8.901E-02	7.747E-05	1.246E-04

a. 50th-percentile value of the fitted line.
b. 84th-percentile value of the fitted line.
c. S1 means 1st 6 months of the year, S2 means 2nd 6 months of the year, Q1 means months 1-3 of the year, Q2 means months 4-6 of the year, Q3 means months 7-9 of the year, Q4 means months 10-12 of the year.

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS
Page 2 of 9

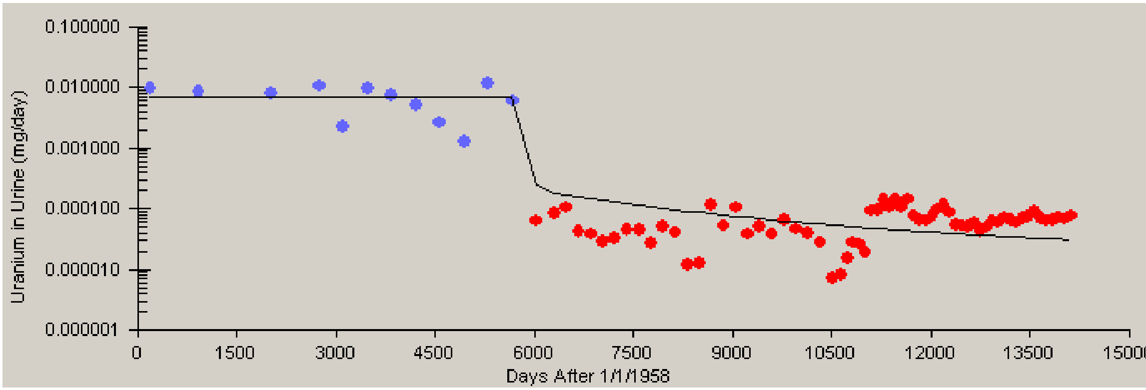

Figure A-1. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type F natural uranium from 1/1/1958 to 12/31/1973 (blue dots).

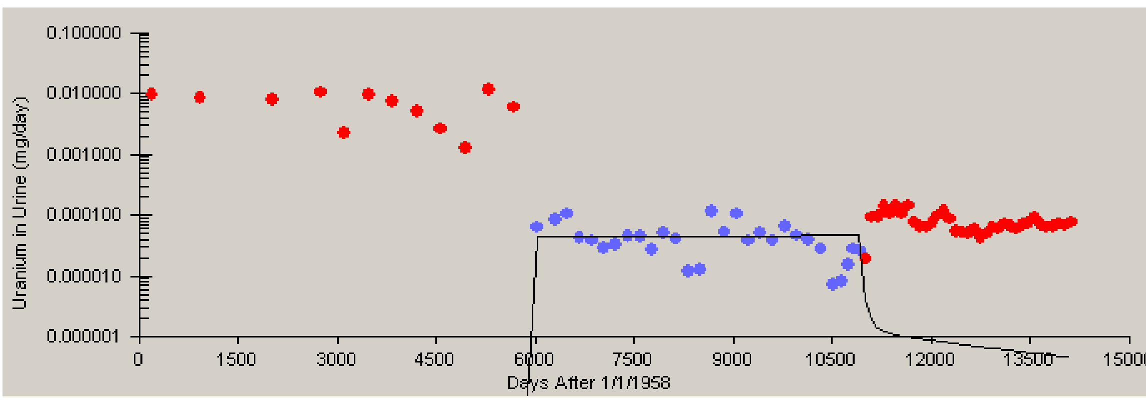

Figure A-2. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type F natural uranium from 1/1/1974 to 12/31/1987 (blue dots).

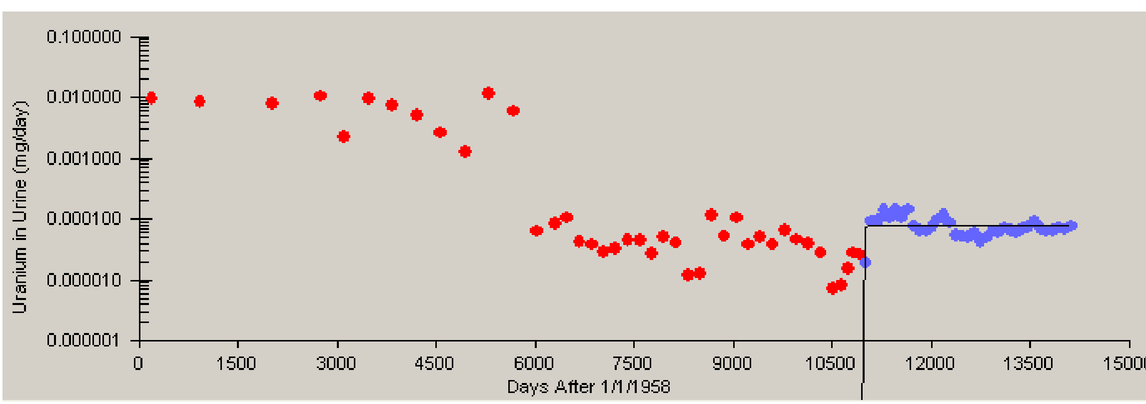

Figure A-3. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type F natural uranium from 1/1/1988 to 12/31/1996 (blue dots).

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS

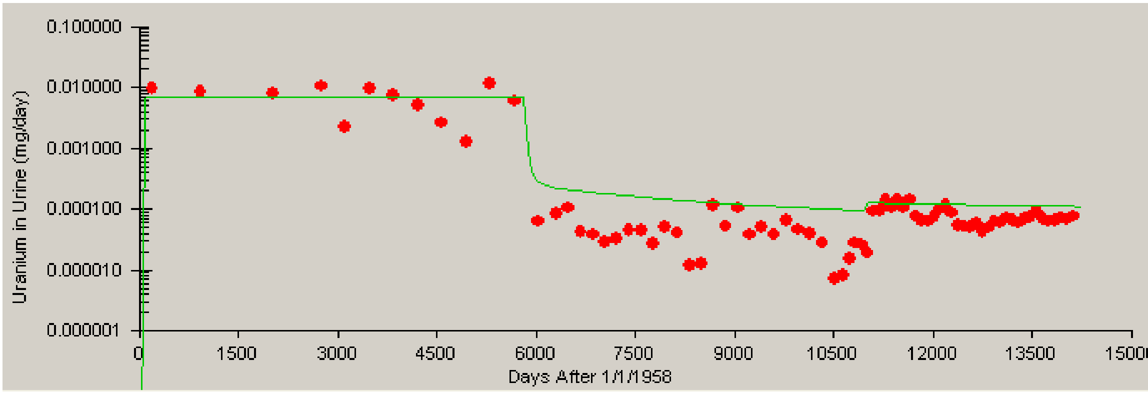

Figure A-4. Predicted and observed 50th-percentile urinary excretion assuming three separate chronic inhalation intakes of Type F natural uranium.

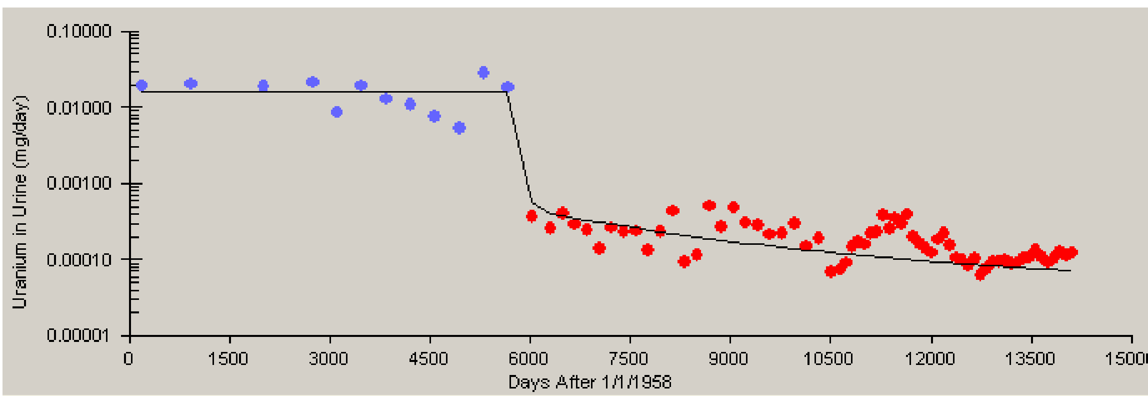

Figure A-5. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type F natural uranium from 1/1/1958 to 12/31/1973 (blue dots).

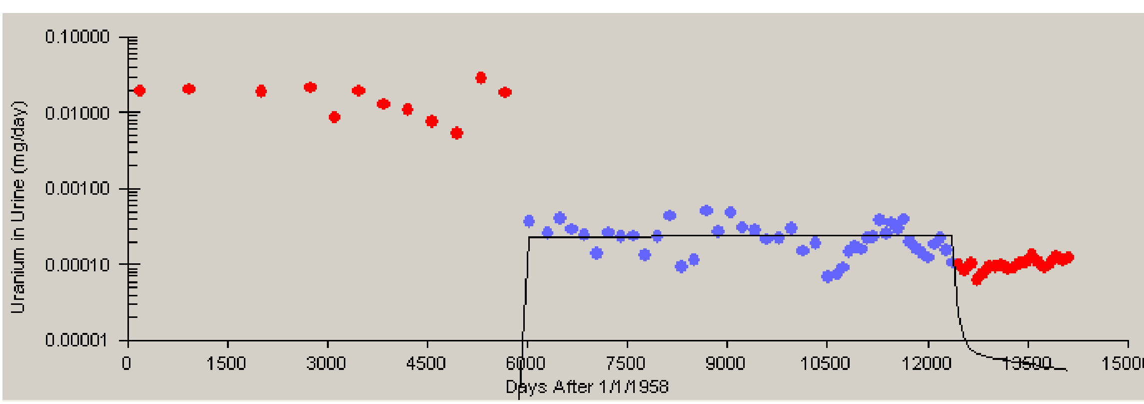

Figure A-6. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type F natural uranium from 1/1/1974 to 12/31/1987 (blue dots).

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS

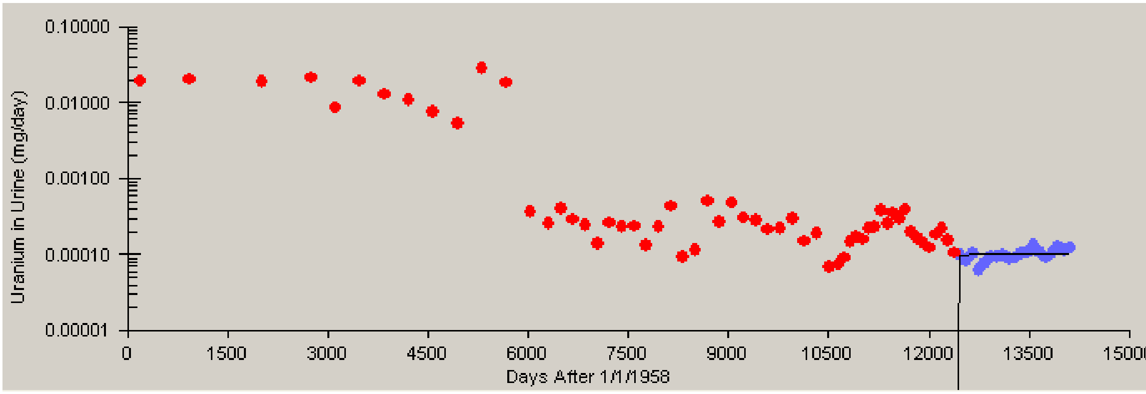

Figure A-7. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type F natural uranium from 1/1/1988 to 12/31/1996 (blue dots).

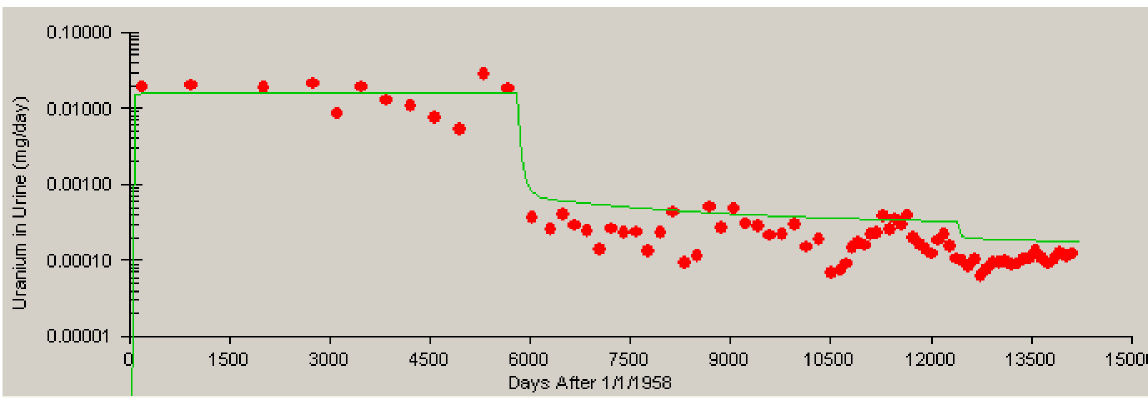

Figure A-8. Predicted and observed 84th-percentile urinary excretion assuming three separate chronic inhalation intakes of Type F natural uranium.

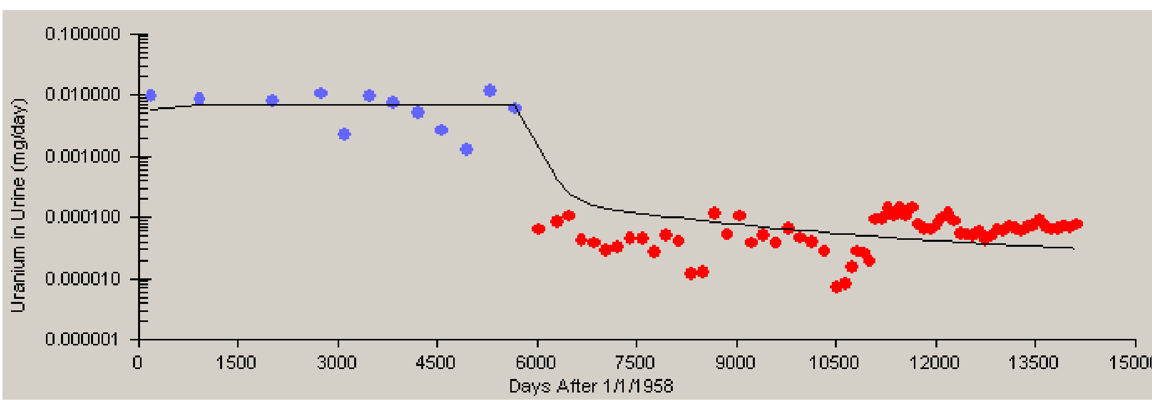

Figure A-9. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type M natural uranium from 1/1/1958 to 12/31/1973 (blue dots).

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS
Page 5 of 9

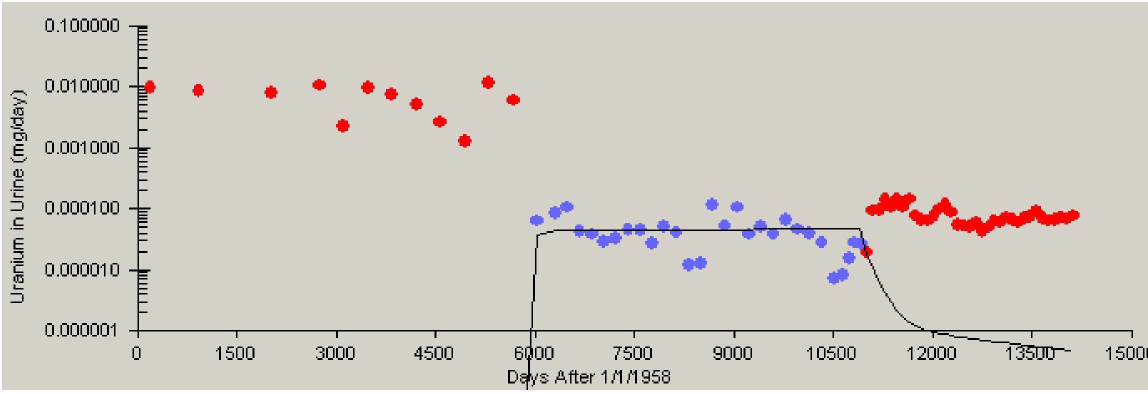

Figure A-10. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type M natural uranium from 1/1/1974 to 12/31/1987 (blue dots).

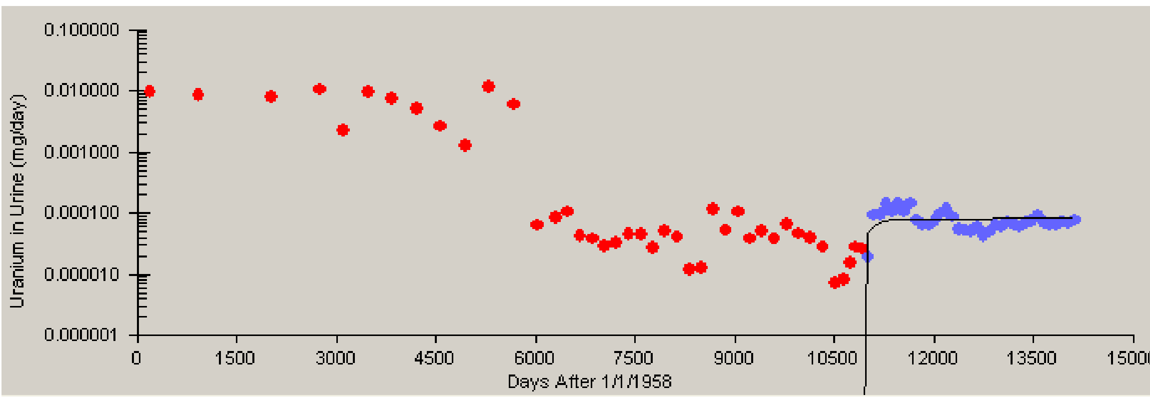

Figure A-11. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type M natural uranium from 1/1/1988 to 12/31/1996 (blue dots).

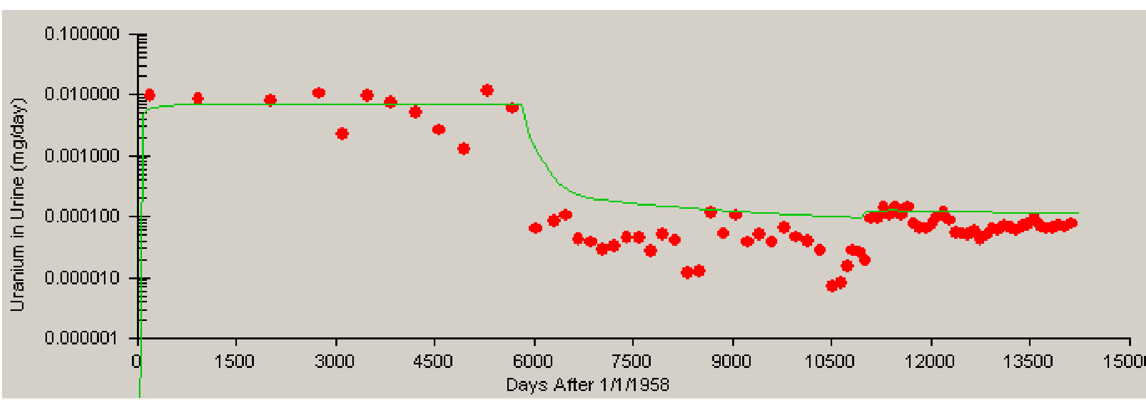

Figure A-12. Predicted and observed 50th-percentile urinary excretion assuming three separate chronic inhalation intakes of Type M natural uranium.

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS
Page 6 of 9

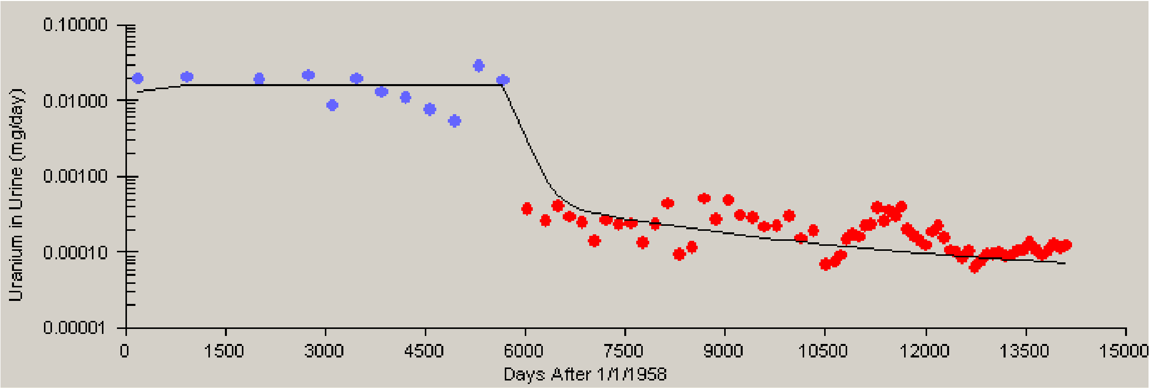

Figure A-13. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type M natural uranium from 1/1/1958 to 12/31/1973 (blue dots).

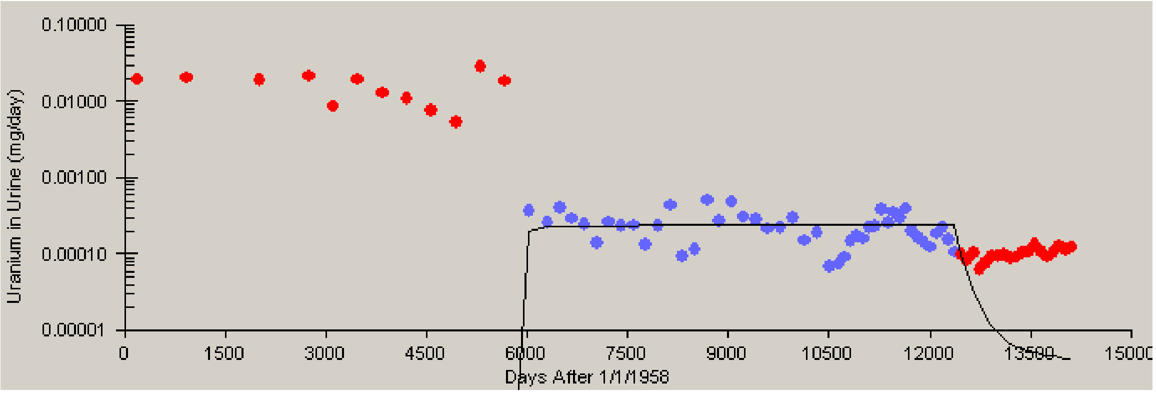

Figure A-14. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type M natural uranium from 1/1/1974 to 12/31/1987 (blue dots).

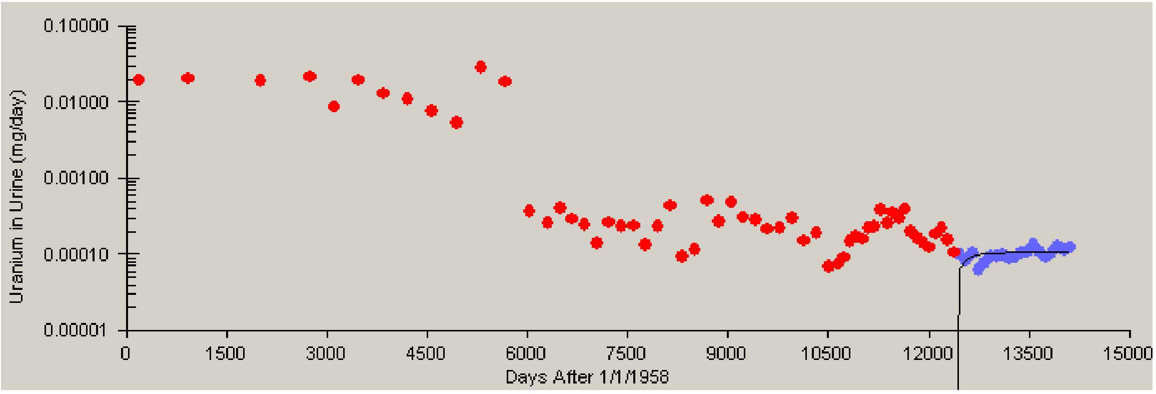

Figure A-15. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type M natural uranium from 1/1/1988 to 12/31/1996 (blue dots).

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS
Page 7 of 9

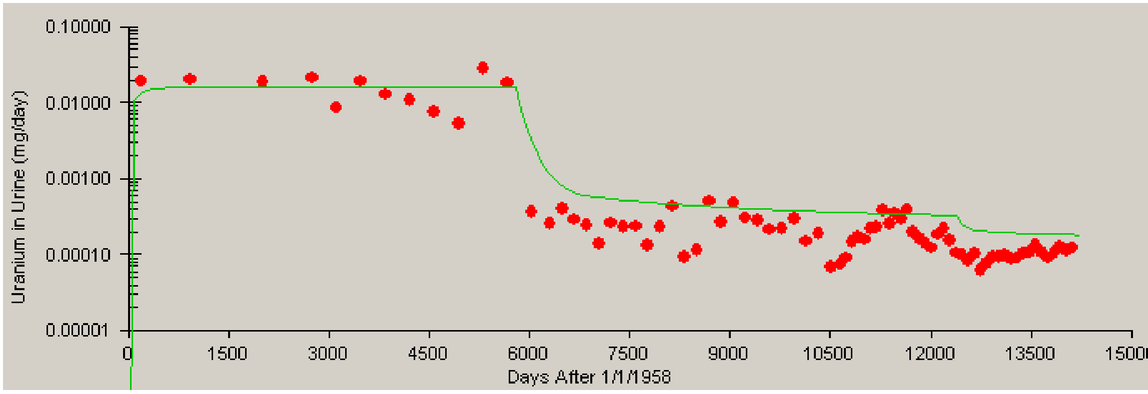

Figure A-16. Predicted and observed 84th-percentile urinary excretion assuming three separate chronic inhalation intakes of Type M natural uranium (blue dots).

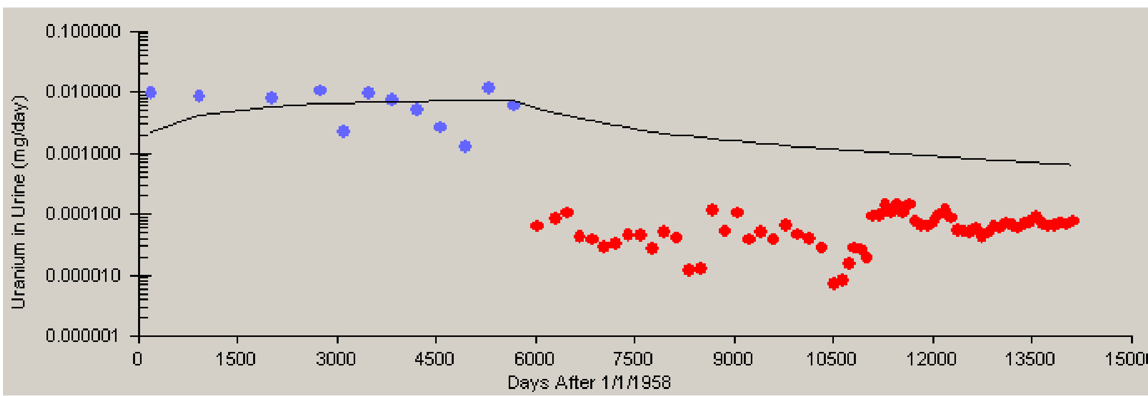

Figure A-17. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type S natural uranium from 1/1/1959 to 12/31/1973 (blue dots).

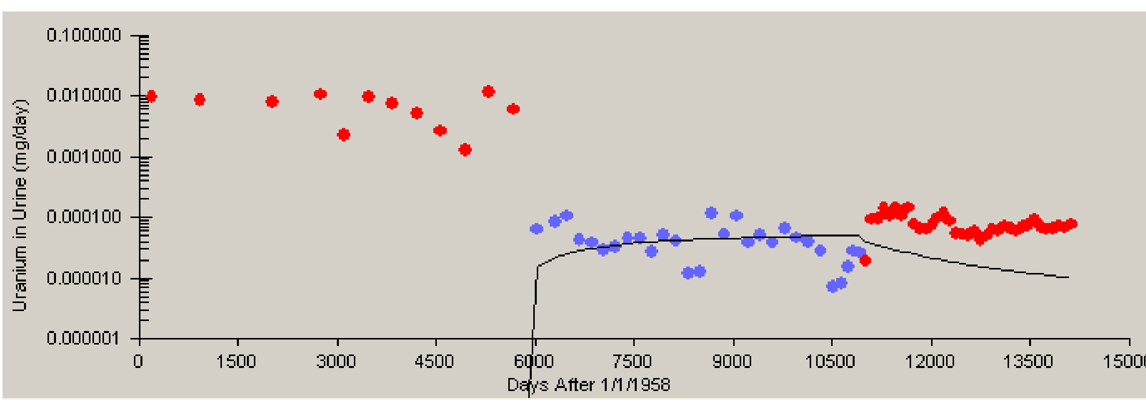

Figure A-18. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type S natural uranium from 1/1/1974 to 12/31/1987 (blue dots).

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS
Page 8 of 9

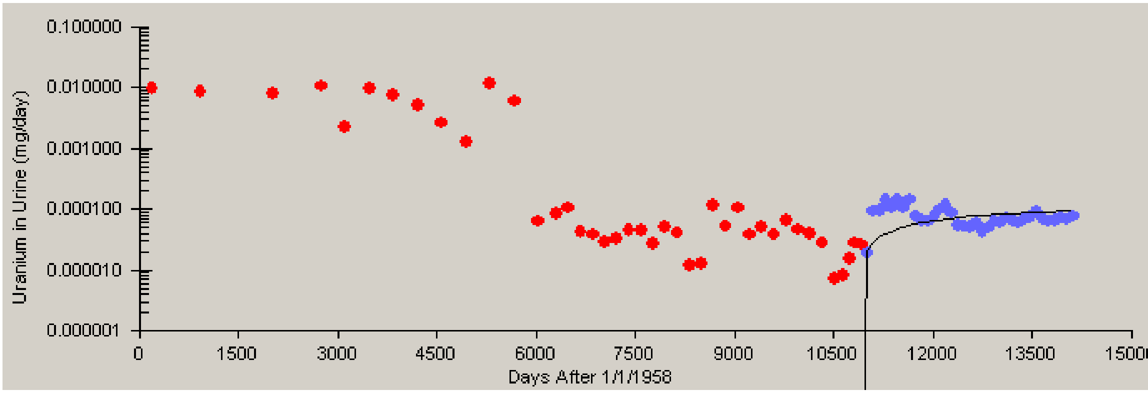

Figure A-19. Predicted and observed 50th-percentile urinary excretion assuming a chronic inhalation intake of Type S natural uranium from 1/1/1988 to 12/31/1996 (blue dots).

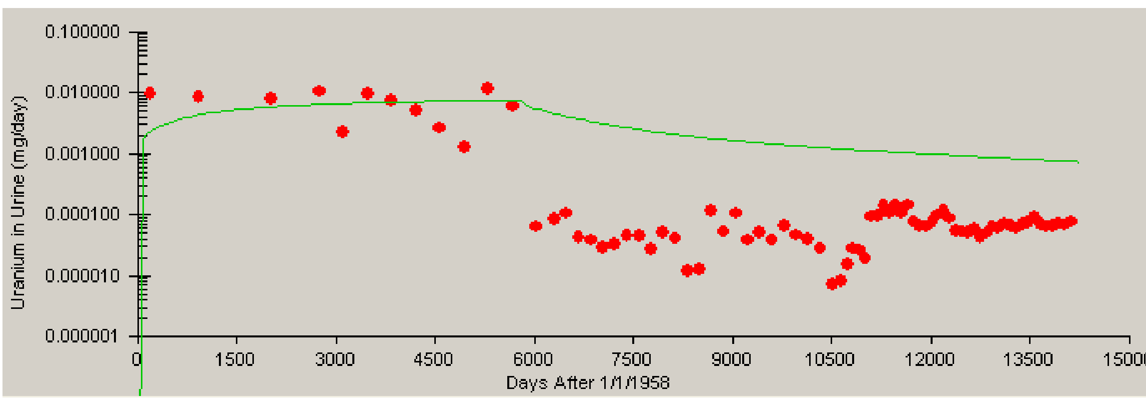

Figure A-20. Predicted and observed 50th-percentile urinary excretion assuming three separate chronic inhalation intakes of Type S natural uranium.

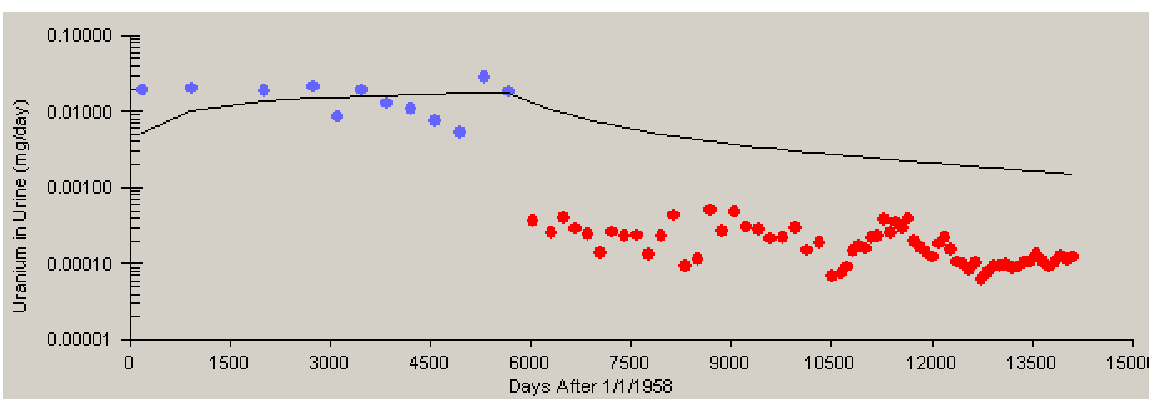

Figure A-21. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type S natural uranium from 1/1/1958 to 12/31/1973 (blue dots).

ATTACHMENT A
STATISTICAL SUMMARIES AND PLOTS
Page 9 of 9

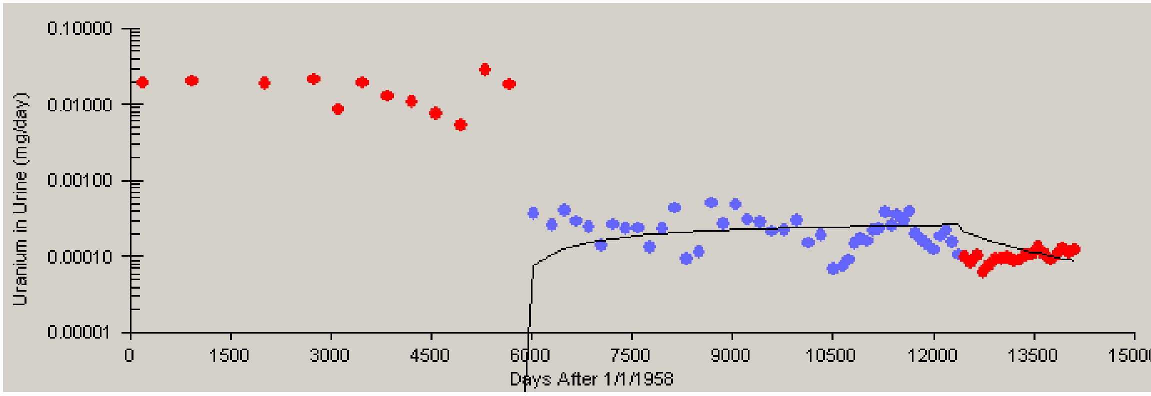

Figure A-22. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type S natural uranium from 1/1/1974 to 12/31/1987 (blue dots).

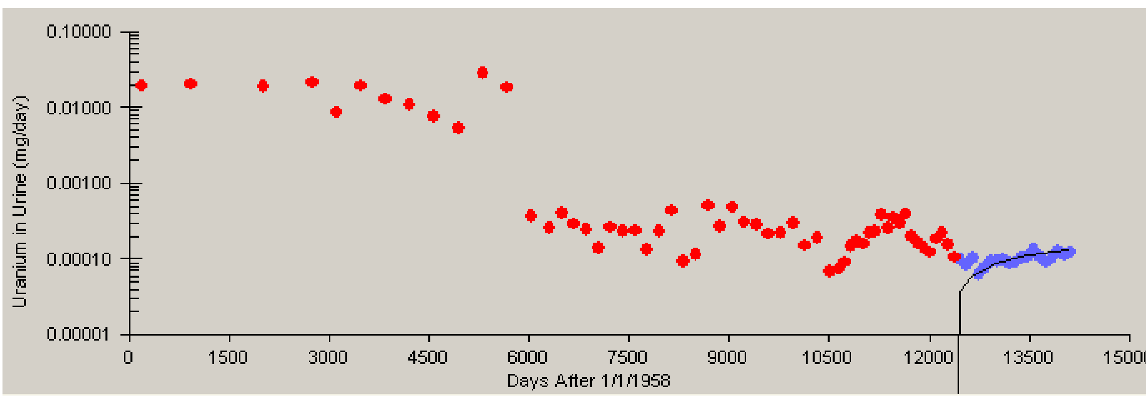

Figure A-23. Predicted and observed 84th-percentile urinary excretion assuming a chronic inhalation intake of Type S natural uranium from 1/1/1988 to 12/31/1996 (blue dots).

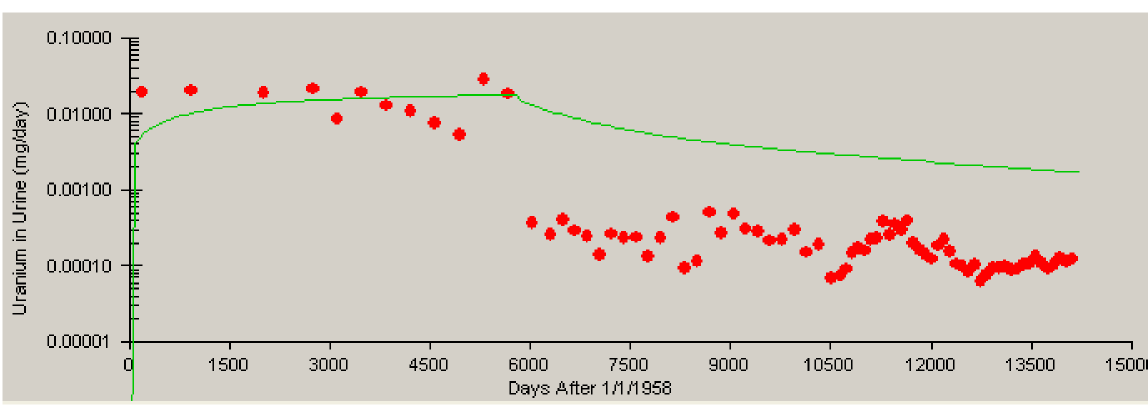

Figure A-24. Predicted and observed 84th-percentile urinary excretion assuming three separate chronic inhalation intakes of Type S natural uranium.